CLAIMS

We claim:

1. A high sensitivity atomic magnetometer comprising
   a) a sensing cell containing a mixture comprising an alkali metal vapor and a buffer gas, wherein the sensing cell is exposed to a background magnetic field lower than a first predetermined value;
   b) means for increasing the magnetic polarization of the alkali metal vapor thereby increasing the sensitivity of the alkali metal vapor to a low intensity magnetic field;
   c) magnetizing means for imposing a magnetic field on a volume of space comprising the sensing cell;
   d) means for probing the magnetic polarization of the alkali metal vapor, the probing means providing an output from the alkali metal vapor, the output comprising characteristics related to the low intensity magnetic field; and
   e) measuring means wherein the measuring means receives the output, determines the characteristics of the low intensity magnetic field, and provides a representation of the low intensity magnetic field;

   wherein the limit of detectability of the atomic magnetometer is lower than a second predetermined value.

2. The atomic magnetometer described in claim 1 further comprising magnetic shielding enclosing a region of space comprising the magnetizing means and the sensing cell.

3. The atomic magnetometer described in claim 1 wherein the first predetermined value is about 10^{-8} tesla.

4. The atomic magnetometer described in claim 1 wherein the second predetermined value is about 1 femtotesla $(Hz)^{-1/2}$.

5. The atomic magnetometer described in claim 1 wherein the density of the alkali metal in the vapor is about 10^{11} cm^{-3} or greater.

6. The atomic magnetometer described in claim 1 wherein the alkali metal is chosen from the group consisting of sodium, potassium, rubidium and cesium.

7. The atomic magnetometer described in claim 1 wherein the alkali metal is potassium.

8. The atomic magnetometer described in claim 1 wherein the buffer gas comprises a noble gas.

9. The atomic magnetometer described in claim 1 wherein the buffer gas comprises one or more isotopes of helium.

10. The atomic magnetometer described in claim 1 wherein the pressure of the buffer gas is in the range from about 1 atm to about 10 atm.

11. The atomic magnetometer described in claim 1 wherein the buffer gas further comprises nitrogen gas.

12. The atomic magnetometer described in claim 1 wherein the sensing cell is maintained at a temperature effective to provide an alkali metal vapor at a density greater than about 10^{11} cm^{-3}.

13. The atomic magnetometer described in claim 1 wherein the sensing cell transmits a plurality of beams of radiation through the alkali metal vapor, wherein at least two of the beams are physically resolved from each other.

14. The atomic magnetometer described in claim 1 wherein the volume of the sensing cell is less than about 200 cm^3.

15. The atomic magnetometer described in claim 1 wherein the means for increasing the magnetic polarization of the alkali metal vapor comprises a first radiation generating means

that generates a first beam of radiation illuminating the alkali metal vapor, the first beam being effective to increase the magnetic polarization of the alkali metal vapor.

16. The atomic magnetometer described in claim 15 wherein the first radiation generating means comprises a first laser device.

17. The atomic magnetometer described in claim 15 wherein the first radiation generating means further comprises a first optical polarizing means that polarizes the first beam of radiation.

18. The atomic magnetometer described in claim 15 wherein the first radiation generating means comprises a first optical polarizing means that imposes linear polarization on the first beam of radiation.

19. The atomic magnetometer described in claim 15 wherein the first radiation generating means comprises a first optical polarizing means that imposes circular polarization on the first beam of radiation.

20. The atomic magnetometer described in claim 15 wherein the first radiation generating means further comprises a first modulator that modulates the first beam of radiation by a first modulation function.

21. The atomic magnetometer described in claim 1 wherein the probing means comprises one or more second radiation generating means that generates one or more second beams of radiation traversing the alkali metal vapor and wherein the output comprises the one or more second beams after they traverse the vapor.

22. The atomic magnetometer described in claim 21 wherein the second radiation generating means comprises a second laser device.

23. The atomic magnetometer described in claim 21 wherein the second radiation generating means further comprises a second optical polarizing means that polarizes the second beam of radiation.

24. The atomic magnetometer described in claim 23 wherein the second radiation generating means comprises a second optical polarizing means that imposes linear polarization on the second beam of radiation.

25. The atomic magnetometer described in claim 23 wherein the second radiation generating means comprises a second optical polarizing means that imposes circular polarization on the second beam of radiation.

26. The atomic magnetometer described in claim 21 wherein the second radiation generating means comprises a second modulator that modulates the second beam of radiation by a second modulation function.

27. The atomic magnetometer described in claim 1 wherein the magnetizing means provides a probing magnetic field in one, two, or all three of the orthogonal directions, x, y , and/or z.

28. The atomic magnetometer described in claim 1 wherein the magnetizing means provides a probing magnetic field modulated by a third modulation function.

29. The atomic magnetometer described in claim 1 wherein the measuring means comprises one or more output detecting means that provides one or more signals comprising characteristics related to the low intensity magnetic field, and one or more signal processing means for receiving the one or more signals and providing the representation.

30. The atomic magnetometer described in claim 29 wherein the output detecting means comprises radiation detecting means that detects a second beam of radiation output from the alkali metal vapor.

31. The atomic magnetometer described in claim 30 further comprising a third optical polarizing means placed between the sensing cell and the radiation detecting means.

32. The atomic magnetometer described in claim 31 wherein the third optical polarizing means comprises a linear polarization analyzer.

33. The atomic magnetometer described in claim 31 wherein the third optical polarizing means comprises a circular polarization analyzer.

34. The atomic magnetometer described in claim 30 wherein the radiation detecting means comprises one or more photodetectors, wherein each photodetector provides a signal comprising characteristics related to the low intensity magnetic field.

35. The atomic magnetometer described in claim 34 wherein the signal comprises a component modulated by a first modulation function or a second modulation function, or both.

36. The atomic magnetometer described in claim 29 wherein the signal processing means receives at least a portion of a signal from the output detecting means, wherein the signal processing means resolves characteristics related to the low intensity magnetic field from the signal and provides a representation thereof, the representation characterizing the low intensity magnetic field detected by the sensing cell.

37. The atomic magnetometer described in claim 36 wherein the signal is modulated by a first modulation function or a second modulation function, or both, wherein the signal processing means detects a component in the signal that is modulated by the first modulation function or the second modulation function, or both.

38. The atomic magnetometer described in claim 29 wherein the measuring means comprises a plurality of output detecting means, wherein a first output detecting means detects radiation traversing a first region of the alkali metal vapor and a second output detecting means

detects radiation traversing a second region of the alkali metal vapor, wherein the first and second regions are different.

39. The atomic magnetometer described in claim 38 wherein the first output detecting means provides a signal to a first signal processing means and the second output detecting means provides a signal to a second signal processing means, and the first signal processing means provides a representation of the low intensity magnetic field sensed in the first region and the second signal processing means provides a representation of the low intensity magnetic field sensed in the second region.

40 . The atomic magnetometer described in claim 38 wherein the distance separating a first region and a second region is about 1 cm or less.

41. The atomic magnetometer described in claim 38 wherein the volume of a region is about 1 cm^3 or less.

42. A high sensitivity atomic magnetometer that generates a representation of a first magnetic field originating within a sample volume, the magnetometer comprising

a) a sensing cell sensitive to low intensity magnetic fields comprising an alkali metal vapor and a buffer gas, the sensing cell being adjacent to a sample volume including a component generating a first magnetic field, wherein the sensing cell is exposed to a background magnetic field lower than a first predetermined value;

b) means for increasing the magnetic polarization of the alkali metal vapor, wherein the magnetic polarization of the alkali metal vapor includes a contribution from the first magnetic field;

c) magnetizing means for imposing a magnetic field on a volume of space comprising the sensing cell;

d) means for probing the magnetic polarization of the alkali metal vapor, the probing means providing an output from the vapor comprising characteristics related to the first magnetic field; and

e) measuring means for receiving the output, determining the characteristics of the first magnetic field, and providing a representation of the first magnetic field;

wherein the limit of detectability of the atomic magnetometer is lower than a second predetermined value.

43. The atomic magnetometer described in claim 42 wherein the sample volume comprises at least a portion of a mammalian subject.

44. The atomic magnetometer described in claim 42 further comprising magnetic shielding enclosing a region of space comprising the magnetizing means, the sample volume and the sensing cell.

45. The atomic magnetometer described in claim 42 wherein the first predetermined value is about 10^{-8} tesla.

46. The atomic magnetometer described in claim 42 wherein the second predetermined value is about 1 femtotesla $(Hz)^{-1/2}$.

47. The atomic magnetometer described in claim 42 wherein the density of the alkali metal in the vapor is is about 10^{11} cm^{-3} or greater.

48. The atomic magnetometer described in claim 42 wherein the alkali metal is chosen from the group consisting of sodium, potassium, rubidium and cesium.

49. The atomic magnetometer described in claim 42 wherein the buffer gas comprises a noble gas.

50. The atomic magnetometer described in claim 42 wherein the pressure of the buffer gas is in the range from about 1 atm to about 10 atm.

51. The atomic magnetometer described in claim 42 wherein the sensing cell transmits a plurality of beams of radiation through the alkali metal vapor, wherein at least two of the beams are physically resolved from each other.

52. The atomic magnetometer described in claim 42 wherein the means for increasing the magnetic polarization of the alkali metal vapor comprises a first radiation generating means that generates a first beam of radiation illuminating the alkali metal vapor, the first beam being effective to increase the magnetic polarization of the alkali metal vapor.

53. The atomic magnetometer described in claim 42 wherein the probing means comprises one or more second radiation generating means that generates one or more second beams of radiation traversing the alkali metal vapor and wherein the output comprises the one or more second beams after they traverse the vapor.

54. The atomic magnetometer described in claim 42 wherein the measuring means comprises one or more output detecting means that provides one or more signals comprising characteristics related to the first magnetic field, and one or more signal processing means for receiving the one or more signals and providing the representation.

55. A method for providing a representation of a low intensity magnetic field detected by a sensing cell that has high sensitivity to a magnetic field, the method comprising the steps of:

a) providing an atomic magnetometer described in claim 1;

b) increasing the magnetic polarization of the alkali metal vapor, thereby increasing the sensitivity of the alkali metal vapor to a low intensity magnetic field;

c) reorienting the magnetic polarization of the alkali metal vapor using a magnetic field;

d) probing the magnetic polarization of the reoriented alkali metal vapor with the probing means, wherein the probing means provides an output whose characteristics are related to the low intensity magnetic field; and

e) receiving the output in the measuring means, determining the characteristics of the low intensity magnetic field, and providing a representation of the low intensity magnetic field detected by the sensing cell.

56. The method described in claim 55 wherein the second predetermined value is about 1 femtotesla $(Hz)^{-1/2}$.

57. The method described in claim 55 wherein the density of the alkali metal in the vapor is about 10^{11} cm^{-3} or greater.

58. The method described in claim 55 wherein the atomic magnetometer further comprises magnetic shielding enclosing a region of space comprising the sensing cell.

59. The method described in claim 55 wherein the alkali metal is chosen from the group consisting of sodium, potassium, rubidium and cesium.

60. The method described in claim 55 wherein the buffer gas comprises a noble gas.

61. The method described in claim 55 wherein the pressure of the buffer gas is in the range from about 1 atm to about 10 atm.

62. The method described in claim 55 wherein the sensing cell transmits a plurality of beams of radiation through the alkali metal vapor, wherein at least two of the beams are physically resolved from each other.

63. The method described in claim 55 wherein the means for increasing the magnetic polarization of the alkali metal vapor comprises a first radiation generating means that generates a first beam of radiation illuminating the alkali metal vapor, the first beam being effective to increase the magnetic polarization of the alkali metal vapor.

64. The method described in claim 55 wherein the probing means comprises one or more second radiation generating means that generates one or more second beams of radiation traversing the alkali metal vapor and wherein the output comprises the one or more second beams after they traverse the vapor.

65. The atomic magnetometer described in claim 55 wherein the magnetizing means provides a probing magnetic field in one, two, or all three of the orthogonal directions, x, y , and/or z.

66. The method described in claim 55 wherein the measuring means comprises one or more output detecting means that provides one or more signals comprising characteristics related to the low intensity magnetic field, and one or more signal processing means for receiving the one or more signals and providing the representation.

67. A method for providing a representation of a first magnetic field originating within a sample volume, the method comprising the steps of:

a) providing a high sensitivity apparatus described in claim 42;

b) identifying a sample volume adjacent to the sensing cell;

c) increasing the magnetic polarization of the alkali metal vapor, wherein the magnetic polarization of the alkali metal vapor includes a contribution from the first magnetic field;

d) reorienting the magnetic polarization of the alkali metal vapor using a magnetic field;

e) probing the magnetic polarization of the reoriented alkali metal vapor with the probing means, wherein the probing means provides an output whose characteristics are related to the first magnetic field; and

f) receiving the output in the measuring means, wherein the measuring means determines the characteristics of the first magnetic field and provides a representation of the first magnetic field detected by the sensing cell.

68. The method described in claim 67 wherein the sample volume comprises at least a portion of a mammalian subject.

69. The method described in claim 67 wherein the second predetermined value is about 1 femtotesla $(Hz)^{-1/2}$.

70. The method described in claim 67 wherein the density of the alkali metal in the vapor is about 10^{11} cm^{-3} or greater.

71. The method described in claim 67 wherein the high sensitivity apparatus further comprises magnetic shielding enclosing a region of space comprising the sample volume and the sensing cell.

72. The method described in claim 67 wherein the first predetermined value is about 10^{-8} tesla.

73. The method described in claim 67 wherein the alkali metal is chosen from the group consisting of sodium, potassium, rubidium and cesium.

74. The method described in claim 67 wherein the buffer gas comprises a noble gas.

75. The method described in claim 67 wherein the pressure of the buffer gas is in the range from about 1 atm to about 10 atm.

76. The method described in claim 67 wherein the sensing cell transmits a plurality of beams of radiation through the alkali metal vapor, wherein at least two of the beams are physically resolved from each other.

77. The method described in claim 67 wherein the means for increasing the magnetic polarization of the alkali metal vapor comprises a first radiation generating means that generates a first beam of radiation illuminating the alkali metal vapor, the first beam being effective to increase the magnetic polarization of the alkali metal vapor.

78. The method described in claim 67 wherein the probing means comprises one or more second radiation generating means that generates one or more second beams of radiation traversing the alkali metal vapor and wherein the output comprises the one or more second beams after they traverse the vapor.

79. The method described in claim 67 wherein the measuring means comprises one or more output detecting means that provides one or more signals comprising characteristics related to the low intensity magnetic field, and one or more signal processing means for receiving the one or more signals and providing the representation.

80. The method described in claim 67 wherein the representation comprises a representation of a source of a first magnetic field occurring within the sample volume displayed in one of three orthogonal Cartesian coordinates referenced to the sample volume.

81. The method described in claim 67 wherein the representation comprises a representation of a source of a first magnetic field occurring within the sample volume displayed in two of three orthogonal Cartesian coordinates referenced to the sample volume.

82. The method described in claim 67 wherein the representation comprises a representation of a source of a first magnetic field occurring within the sample volume displayed in three of three orthogonal Cartesian coordinates referenced to the sample volume.